Managing Urban Shallow Geothermal Energy

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Deliverable D 4.3

Documented thematic output datasets for web presentation of selected pilot areas

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Content

1 INTRODUCTION 3

1.1 Description of the deliverable 3

1.2 Scope of the deliverable 3

2 FINAL OUTPUT DATASETS 4

2.1 Datasets per category 7

2.2 Datasets per pilot area 8

2.3 Datasets per data format 9

3 DEVIATIONS FROM THE PRELIMINARY DATA DELIVERY PLAN 10

4 SUMMARY AND CONCLUSION 12

5 ANNEX 13

1 INTRODUCTION

1.1 Description of the deliverable

The thematic output datasets represent spatial datasets (GIS based vector- and raster datasets as well as 3D datasets), which will be compiled by the task leaders and transferred to WP5 for later web hosting. All datasets produced will be accompanied by annotation reports, which will also be published on the GIP related web platform.

1.2 Scope of the deliverable

The first part of the report comprises a summary of all output datasets, that have been elaborated in the pilot areas. They describe resources (geological and hydrogeological base datasets as well as capacity and energy related datasets), limitations of use and results of field/laboratory measurements related to the use of shallow geothermal energy. Geological and hydrogeological datasets as well as the results of field measurements are useful for all shallow geothermal energy systems. Our estimations for heating or cooling capacity and energy content in place for heating or cooling focus on open loop systems (groundwater heat exchangers) and closed loop systems (borehole heat exchangers), the two most commonly used shallow geothermal technologies in Europe.

In the second part of the report we briefly explain deviations from our initial data delivery plan. Some output datasets we aimed at changed their names or units over the course of the project, or were disregarded due to various reasons. A comparison between the initial and the final data delivery plan documents and explains the changes.

The output datasets listed in this deliverable are strongly connected to the following other MUSE deliverables:

- General statistics about the output datasets, which have been elaborated for the pilot areas, will be given here. The report **D 4.2 "Summary report about the outcomes in the pilot areas"** describes the work inside the pilot areas in more detail.
- The report **D 2.1 "Catalogue of evaluated methods and guidelines on exploration, assessment and technical monitoring of shallow geothermal energy use in urban regions"** summarizes all methods and workflows that have been applied to create the output datasets. Here one can also find recommendations and lessons learned about them for future applications.
- All output datasets listed in this report are visualized on our official pan-European EGDI map viewer for MUSE that can be addressed by the following LINK. The report **D 5.4 "Guideline on the use of the SGE web platform tools at the Information platform"** provides information about the functionalities of the MUSE web platform. The overall map viewer also includes links to 14 separate maps for each MUSE pilot area. Publicly available datasets are also available for download from the map viewers.
- The report **D 5.3 "Guideline on the delivery of geodata and knowledge related to SGE to the GeoERA Information Platform",** which was prepared in the initial phase of the MUSE project to set the standards and goals for the data delivery, includes a preliminary list of all datasets aimed at for preparation.

2 FINAL OUTPUT DATASETS

A total of 156 output datasets have been prepared for 14 pilot areas based on a list of 50 different parameters (Table 1). All output data sets from all pilot areas are listed in Annex 1.

Table 1: Overview of output parameters that have been elaborated at least in one pilot area. OLS = open-loop resources, CLS = closed-loop resources, LOU = Limitation of use, FM = Field measurements, GI = General information, GEO = Geology. R = Raster, V= vector, pt = point, pl = polyline, pg = polygon. No = Number of pilot areas covered by the specific dataset

Parameter name	Category	Unit	Short description	Data format	No
Annual thermal load - closed loop system	CLS	MWh/a	The annual amount of thermal energy available to be used with a specified closed loop system.	R	1
Average interval bulk thermal conductivity	CLS	W/m/K	Average thermal conductivity (including unsaturated zone) for a specific depth interval not accounting for advective effects caused by ground water.	R	5
Average interval subsurface temperature	CLS	°C	Estimated annual average subsurface temperature for a given depth interval.	R	5
Heat transfer rate	CLS	W/m	Maximum heat transfer rate (heating, cooling) related to borehole heat exchangers (BHE) for a defined depth interval.	R	1
Land surface temperature	CLS	°C	Temperature of the land surface on the top canopy layer.	R	9
Specific annual thermal load - closed loop systems	CLS	kWh/m²/a	Specific annual thermal energy content for heating and / or cooling referring per surface area for borehole heat exchangers at a defined length.	R	1
Specific thermal capacity - closed loop systems	CLS	W/m²	Specific thermal capacity per surface area unit for borehole heat exchangers of a defined length.	R	1
In-situ Thermal conductivity of unconsolidated sediments	FM	W/m/K	Measured thermal conductivity of partly unconsolidated sediments based on needle-probe sensors at in-situ saturation conditions	V: pt	1
Measured electrical conductivity	FM	µS/cm	Observed electric conductivity of groundwater bodies at a defined depth interval or for a single point in depth based on surveys, which have been executed in the framework of MUSE or are linked to the work in MUSE.	V: pt	1
Measured groundwater depth	FM	m	Observed depth above or below sea level at which the surface of groundwater stands.	V: pt	2
Measured groundwater level	FM	m above sea level	Observed elevation above or below sea level at which the surface of groundwater stands	V: pt	3
Measured groundwater temperature	FM	°C	Observed groundwater temperature at a defined depth interval or for a single point in depth based on surveys.	V: pt	2
Measured subsurface temperature profiles	FM	degC	Temperature profiles measured in boreholes or vertical borehole heat exchangers.	V: pt	4

Observed hydraulic conductivity	FM	m/s	Hydraulic conductivity derived from field measurements e.g. pumping tests or sieving grain analysis	V: pt	2
Observed specific yield	FM	m3/h/m	Measured amount of water per hour and meter drawdown characterizing the hydraulic productivity of a specific well.	V: pt	1
Thermal conductivity of hardrock samples	FM	W/m/K	The intrinsic ability of hard rock samples to conduct heat.	V: pt	1
Decision support map for the use of shallow geothermal use	GI	None	General map evaluating the suitability and preference of open loop and closed loop shallow geothermal systems. Pgease note that horizontal loop systems are not considered.	V: pg	1
Traffic light map closed loop system	GI	None	Overall evaluation of possible limitations and restrictions to the installation of closed loop systems based on a 3 colour schemes (pink: no installation allowed, yellow: installation based on case to case decision, green: no restrictions known)	V: pg	3
Traffic light map open loop system	GI	None	Overall evaluation of possible limitations and restrictions to the installation of open loop systems based on a 3 colour schemes (pink: no installation allowed, yellow: installation based on case to case decision, green: no restrictions known)	V: pg	2
Depth of a geological boundary	GEO	m	Contour map of the depth of a defined geological boundary relevant for the use of shallow geothermal energy (e.g. bedrock surface).	R	3
Elevation of a geological boundary	GEO	m above sea level	Contour map of the elevation of a defined geological boundary relevant for the use of shallow geothermal energy (e.g. bedrock surface).	R	4
Existing geological profiles and cross-sections	GEO	None	Observed or interpreted geological borehole profiles or cross-sections referring to stratigraphic or lithological units.	V: pl, pt	5
Geomagnetic characterization	GEO	nT	Interpreted maps derived from geomagnetic surveys performed in or linked to MUSE.	V: pt	1
Compressible ground	LOU	None	Hazard for subsidence due to unconsolidated sediments	V: pg, pt	1
Confined or artesian groundwater zones	LOU	None	Drilling for shallow geothermal energy use in confined or artesian groundwater needs extra caution	V: pg, pt	3
Critical composition of groundwater	LOU	None	Groundwater zones of problematic chemistry related to shallow geothermal energy	V: pg, pt	2
Faults	LOU	None	A contact separating two bodies of material across which one body has slid past the other.	V: pl	3
Flood hazard	LOU	None	Zones possibly affected by periodic flooding.	V: pg	3
Groundwater protection	LOU	None	Areas dedicated to drinking water or curative water supply, which might limit the use of shallow geothermal energy	V: pg	9
Landslide	LOU	None	Processes of downhill slope movements of soil, rock, and organic materials related to different types of ground failure.	V: pg, pt	3
Mining area	LOU	None	Locations of open pit and/or underground mining	V: pg, pt	2
Natural reserves	LOU	None	Protected area of importance for wild life flora or fauna.	V: pg	7

Other groundwater use	LOU	None	Groundwater uses, which might limit the use of shallow geothermal energy	V: pt	7
Potentially karstified zones	LOU	None	Areas with rocks susceptible to karstification	V: pg, pt	2
Shallow geothermal energy system	LOU	None	Installations that enable the use of the energy stored underground in a depth of up to 300 to 400 meters.	V: pt	8
Subsurface infrastructure	LOU	None	Any subsurface installations, which might lead to conflicts with drilling wells and borehole heat exchangers	V: pl	3
Uncontrolled hazardous waste landfills	LOU	None	Uncontrolled landfill or major dumpsite with suspicion or recorded hazardous substances in substantial amounts	V: pg, pt	4
Areas suited for groundwater disposal to surface waters or municipal drains	OLS	None	Areas suited for groundwater disposal to surface water or municipal drains. Relevant for areas where thermally used groundwater may not be possible to be injected to the groundwater for legal or technical reasons.	V: pg, pt	1
Groundwater body suitable for open-loop systems	OLS	None	Outline of a distinct volume of groundwater within an aquifer or system of aquifers, which is hydraulically isolated from nearby groundwater bodies and provides enough yield with suitable temperatures for open-loop systems with and/or without thermal storage.	V: pg	8
Hydraulic conductivity	OLS	m/s	Interpolated or modelled hydraulic conductivity of a groundwater body suitable for the appgication of open loop systems.	R	4
Hydraulic productivity	OLS	l/s	Maximum yield or pumping rate of a groundwater well doublet per square meter at a given location.	R	4
Hydraulic transmissivity	OLS	m²/d	Maximum yield of a groundwater well at peak load referring to the hydraulic conditions at the groundwater body (either maximum drawdown or maximum raise of water level in a well) for a defined well diameter.	R	3
Maximum groundwater temperature	OLS	°C	Maximum groundwater temperature for a designated period of time	R	1
Minimum groundwater temperature	OLS	°C	Minimum groundwater temperature for a designated period of time	R	3
Net aquifer thickness	OLS	m	Water saturated thickness of a groundwater body	R	6
Specific annual thermal load - open loop systems	OLS	kWh/m²/a	Energy content available in a defined volume of a groundwater body for heating and/or cooling applications. This parameter may consider summation effects caused by existing installations or other anthropogenic influences.	R	3
Specific capacity	OLS	m3/h/m	Extracted water volume per hour and meter drawdown for a defined well diameter.	R	1
Specific yield	OLS	%	Ratio of the volume of water that a given mass of saturated rock will yield by gravity to the volume of that mass.	R	2
Thermal capacity - open loop systems	OLS	kW	Thermal capacity of a well doublet for heating and/or cooling depending on the hydraulic productivity and the thermal productivity.	R	3
Thermal productivity	OLS	°C	Maximum temperature shift between the production and the injection well possible with regard to legal or ecological limitations.	R	1

15 output parameters are only prepared for one pilot area, all others have been produced for at least 2 pilot areas. The datasets which have been chosen by most pilot areas are land surface temperature and groundwater protection area (both 9 pilot areas) and existing shallow geothermal energy systems and groundwater body suitable for open-loop systems (both 8 pilot areas).

2.1 Datasets per category

All output parameters have been assigned to the 6 categories shown in Figure 1. The majority of the produced datasets falls into the category limitation of use, as this is also the category with the most parameters available. Generally, more parameters have been identified and selected by the partners to describe resources for open-loop systems compared to closed-loop systems. The share of the categories from the output datasets produced (right in Figure 1) resembles the share of categories of the final parameter list (left in Figure 1), indicating an even distribution.

Figure 1: Categories of all 50 output parameters available (left) and of all 156 output datasets elaborated for the MUSE pilot areas (right).

2.2 Datasets per pilot area

Based on their focus and their budget for the project, the MUSE partners elaborated different amounts and different types of output datasets. A summary of the numbers and categories of the datasets per pilot area is presented in Figure 2. The mean number of produced output datasets for all 14 pilot areas is 11. Pilot areas, for which the most datasets were created are Cork (24), Bratislava (20) and Vienna (17). The British Geological Survey was responsible for two pilot areas, Glasgow and Cardiff. They set the focus on Cardiff and therefore for Glasgow only one dataset was produced.

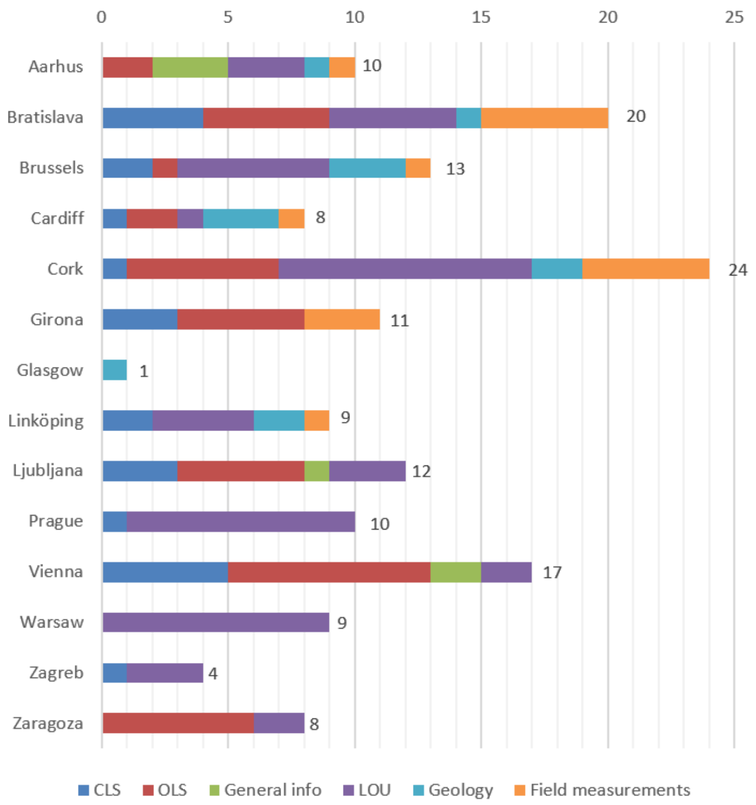

Figure 2: All output datasets per pilot area based on category. CLS = closed-loop system, OLS = open-loop system, LOU = limitation of use. Number next to the bar indicates the total number of output datasets.

2.3 Datasets per data format

The output datasets comprised raster and vector format (see Table 1). Most resources for open-loop and closed-loop systems are displayed as raster datasets, whereas vector format prevails for field measurements and limitation of use datasets. Regarding the visualisation of resources, limitations of use and exploration for shallow geothermal energy systems, one cannot focus on one data format and disregard the other. Both formats are important, as the distribution of vector and raster datasets from the pilot areas in Figure 3 shows.

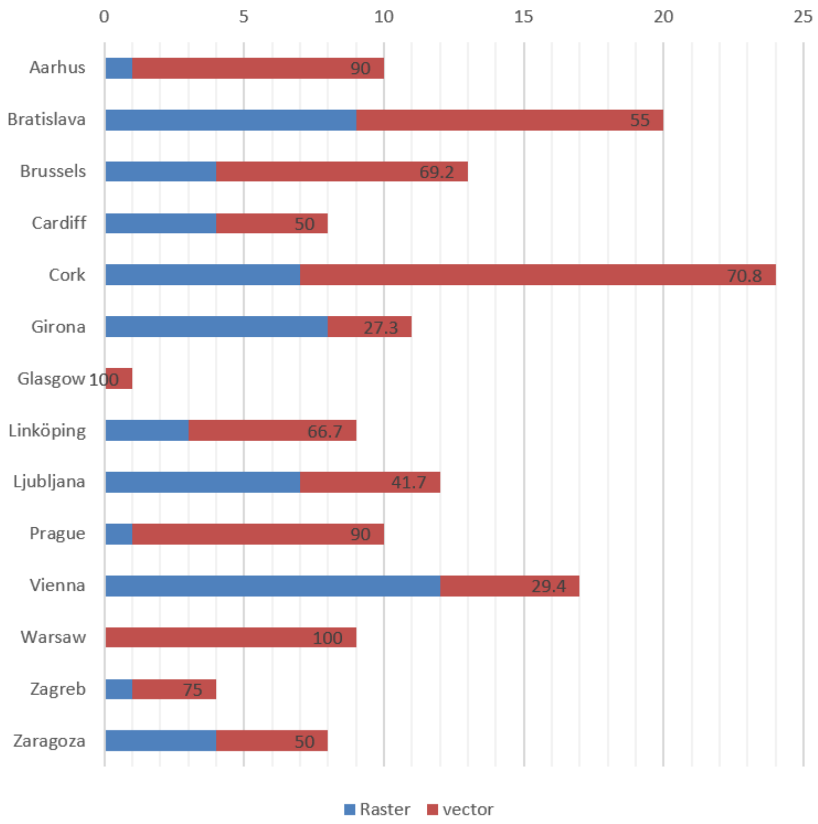

Figure 3: Output datasets per pilot area classified by data format (Raster or vector). The number in the bar indicates the percentage of vector datasets.

3 DEVIATIONS FROM THE PRELIMINARY DATA DELIVERY PLAN

The initial version of the data delivery plan, which is part of D 5.3 ”Guideline on the delivery of geodata and knowledge related to SGE to the GeoERA Information Platform”, comprised 58 output datasets. Already during the preparation of this preliminary data delivery plan it became obvious that MUSE won’t focus on 3D datasets, as the partners did not request them. 3D modelling was used indeed in the process of elaborating output parameters in some pilot areas, however the format of the resulting datasets were rasters.

During the course of the project some parameters were disregarded entirely or joined to others to avoid having similar or redundant outputs. For some resource parameters we changed the units or names while the content remained the same, as during the elaboration of the datasets more user-friendly units or terms became evident. Table 2 shows the parameters with major amendments.

Table 2: Disregarded or changed parameters from preliminary data delivery plan. Cat. = Category, CLS = Closed-loop resources, LOU = Limitation of use, GS =Geothermal storage, GEO = Geology, FM = Field measurements, OLS = Open-loop resources

Parameter	Cat.	Unit	Short description	Amendment
Average interval temperature gradient	CLS	degC/ 100m	Effective temperature gradient for a defined depth interval in the subsurface. The gradient might also consider non-conductive or transient effects (Input parameter for estimating the heat transfer rate).	Was used as input data set for average interval subsurface temperature, which is the more relevant parameter.
Thermal conductivity at a specific geological boundary	CLS	W/m/K	Distribution of the thermal conductivity for a geological boundary of surface relevant for shallow geothermal energy use (e.g. bedrock surface).	Was included into the parameter bulk thermal conductivity.
Observed ground stability problems	LOU	None	Risk for subsidence or uplift due to unconsolidated sediments and problematic rock types like anhydrites, gypsum or karstified rocks.	Name and meaning was changed into “compressible ground”. Other ground stability problems have separate parameters.
Zones with restrictions to drilling	LOU	None	Drillings are not allowed for any reason.	Was not relevant in any of the MUSE pilot areas – disregarded.
Interval thermal conductivities (TRT measurements)	FM	W/m/K	Measured effective average interval thermal conductivity also accounting for advective heat transport caused by groundwater. The data are obtained from Thermal Response Test measurements).	TRTs were not in the focus of MUSE and no pilot area selected this parameter – disregarded.
Thermal Response Tests (TRT)	FM	None	Results of field parameters derived from Thermal Response Test Measurements covering: interval thermal conductivities, heat transfer	TRTs were not in the focus of MUSE and no pilot area selected this parameter – disregarded.

			rates and subsurface temperature profiles.	
Lithology of a specific geological unit or boundary	GEO	None	Averaged lithological composition of a defined geological unit (volumetric averaging of harmonized lithological components) or distribution of different rock types at a geological boundary (e.g. bedrock surface).	Was too similar to depth/elevation of geological boundary – disregarded.
Effective thermal diffusivity	GS	m^2/s	Thermal diffusivity of a defined depth interval. The parameter describes how quickly the terrain reacts to a change in temperature characterizing unsteady heat conduction and can be applied to evaluate BTES storage.	Was not relevant in any of the MUSE pilot areas – disregarded.
Zones of limited injectivity	OLS	none	Injection rate per well is expected to be reduced compared to the production rate due to lithological or biochemical (skin factor). More injection wells or larger diameter of injection wells needed compared to production wells.	Was not relevant in any of the MUSE pilot areas – disregarded.
Groundwater bodies suitable for Aquifer Thermal Energy Storage (ATES)	GS	None	Basic layer showing the outlines of groundwater bodies suitable for ATES use. The evaluation may base on joint evaluation criteria.	Was included in suitability of groundwater for open-loop systems.

4 SUMMARY AND CONCLUSION

We achieved our goal to create datasets for all selected output parameters in at least one MUSE pilot area. We produced a total of 156 output datasets for 14 pilot areas. These datasets serve as demonstration datasets linked to the jointly developed methods and workflows, which are described in the report D 2.1 "Catalogue of evaluated methods and guidelines on exploration, assessment and technical monitoring of shallow geothermal energy use in urban regions". Many parameters have been produced for different countries all over Europe, indicating that our workflows are applicable in different socio-economic, climatic and geological settings.

Nevertheless, some initially planned parameters had to be disregarded. They were identified as not significantly contributing to the goals of MUSE and disregarded completely or joined with other parameters. For some resource parameters we changed the units or names while the content remained the same, as during the elaboration of the datasets more user-friendly units or terms were developed.

Due to limited budget and time until the end of the project, the initial plan to test different workflows in the same pilot area for comparison reasons was not achieved. This is an open task for future collaboration between the partners.

The produced datasets for the GeoERA Information Platform in the MUSE pilot areas have a clear focus on open-loop systems. This means in many pilot areas shallow groundwater is available and emphasizes the importance of an efficient groundwater management for shallow geothermal energy use in urban areas. This is not surprising: Settlement started in areas close to big rivers, which developed into our nowadays modern cities. The abundant shallow groundwater that lies often within the sediments deposited by those rivers is now a powerful resource for shallow geothermal energy that should be used efficiently and sustainably. The database that was built in the MUSE pilot areas provides a first step towards an integrative management of shallow groundwater bodies.

5 ANNEX

1 Final data delivery plan